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Optimizing input and output chirps up to the third-order for sub-nanojoule, ultra-short pulse compression in small core area PCF

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ABSTRACT Compression of sub-nanojoule laser pulses using a commercially available photonic crystal fiber (PCF) with zero dispersion wavelength of 860 nm is discussed. A twofold pulse compression starting from 24 fs transform limited seed pulses around 800 nm is experimentally demonstrated as a verification of our simulations. Theory shows that by the optimization of input and output chirp parameters up to the third order, high quality, 5.7 fs pulses can be generated from a cost efficient experimental setup. Further calculations show that 1 ps pulses with central wavelength of 800 nm can be compressed down to 50 fs in the normal dispersion regime of the fiber with proper dispersion compensation. Calculations also show that dispersion flattened fibers can improve both the quality and the duration of compressed pulses.

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1 Introduction

Pulse compression of optical pulses down to 5 fs were demonstrated in a wide variety of experimental arrangements using standard single mode optical fiber (SMF) [1] or gas filled hollow core fiber as a nonlinear medium [2]. The common feature with previous studies in this time scale is that they require laser pulses at energy levels well above 10 nJ, i.e., pulse energies that are difficult to obtain directly from a femtosecond pulse laser oscillator. As a result of recent development of small effective core area, single mode photonic crystal fibers (PCF), tenfold pulse compressions were demonstrated in a few experiments [3, 4] at nJ or sub-nJ optical pulse energies, which resulted in typical compressed pulse durations of 20 to 35 fs. Recently, the possibility of compressing supercontinuum generated in a 5 mm long microstructured fiber was also reported [5]. In this later experiment, 15 fs transform limited pulses obtained from a low repetition rate Ti:sapphire oscillator were compressed down to 5.5 fs using an adaptive compression technique based on spectral-phase interferometry for direct electric–field reconstruction (SPIDER).

In this paper, we show that it is possible to obtain compressed sub−6 fs pulses using nanojoule or sub-nanojoule seed pulses around 800 nm by utilizing only small core area PCF and prism pair/chirped mirror compressors. In a previous study [3], we have found that the compressed pulse duration was primarily limited by the maximum available wavelength difference between the laser central wavelength (750 nm) and the zero dispersion wavelength (767 nm) of the PCF sample. Novel PCFs with red-shifted zero dispersion wavelengths, however, can improve both the quality and the duration of the compressed pulses when we choose input and output chirp compensation parameters properly. It is worth pointing out that 1 nJ seed pulse energies with the required pulse durations can be obtained easily from low pump threshold, mode-locked Ti:sapphire laser oscillators pumped by only 1.2 W at 532 nm [6].

As a proof of our calculations, we describe our corresponding experiment with similar experimental conditions as the simulations had. We also extend our studies for compression of sub-nJ pulses with initial time duration at around 1 ps. Later, we discuss the possibility of building cost efficient, compact sub−100 fs laser sources by utilizing nonlinear spectral broadening and dispersion compensation. As a seed pulse, we consider low cost, compact ultrashort pulse laser diodes with transform limited pulse duration of around 1 ps [7, 8]. Their typical pulse energy is well below 1 nJ, which does not result in considerable spectral broadening in standard single mode-fibers. However, nonlinear spectral broadening (and possibly amplification) in doped [9] small core area PCFs allows the reduction of the pulse duration to the sub-100 fs regime. Previously, this time domain could only be achieved by more expensive solid-state lasers.

2 Theory

We calculate the pulse propagation through PCFs as a nonlinear Schrödinger type system [10]. The input pulses used in our simulation exhibit a sech^2 temporal intensity envelope function that is typical for femtosecond solid-state laser oscillators. We used dispersion data provided by the manufacturer (type “2.2 nonlinear PCF” fiber, crystal fibre, Denmark [11]) in our calculations. Since the dispersion was not

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